SSC-SR-1002

SUPERCOLLIDER

PROGRAM PLAN

PHASE I

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SSC CENTRAL DESIGN GROUP
c/o Lawrence Berkeley Laboratory
Berkeley, California 94720

SUPERCOLLIDER PROGRAM PLAN

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SSC PROGRAM PLAN

1. INTRODUCTION

The purpose of this plan is to describe the Research and Development activities associated with the SSC (Superconducting Super Collider) Phase I program. This Phase I program will provide a comprehensive conceptual design report and is geared to accomplish specific research and development objectives that are required prior to initiation of Construction (Phase II). The overall program objectives are given in Section 2. The plan for assuring that these objectives are attained is described in the SSC Management Plan. An overall description of the planned program is provided in Section 5. This Phase I program follows an extensive Reference Design Study conducted for the purpose of assessing technical feasibility and probable costs.

The SSC will be a high energy high-luminosity hadron collider similar to that described in the SSC Reference Designs Study Report of May 1984. The planned Conceptual Design Report will describe the technical and conventional facilities for the SSC, together with Cost, Schedule and Manpower requirements. It will also address Environmental, Safety, Quality Assurance, Operations, Reliability, and Maintainability issues. The experimental areas will be studied to maximize the High Energy Physics research potential.

A comprehensive Research and Development program will take place over the next three years to arrive at a cost and performance optimized design. This program will also serve to demonstrate that the key technical features of the

accelerator-collider system proposed for the SSC are achievable within the estimated construction cost and schedule. The R&D effort will also include assessment of the requirements for the initial complement of detectors for the projected SSC physics research effort.

The Phase I program will provide a site parameters document and other site information, as required for DOE's site selection process. The site parameters document will be specific to those technical features of the SSC which are related to the physical conditions of the site.

The Phase I national effort will be carried out under the direction of a Central Design Group (CDG) located at Lawrence Berkeley Laboratory. The CDG, working in concert with DOE, will direct and coordinate the SSC design and associated R&D activities at the Design Center, at existing Laboratories and Universities, and at Industrial and A/E firms. The CDG is directed by Dr. M. Tigner who reports to the Universities Research Association (URA) Board of Overseers which has been specifically created for this activity.

The SSC Phase I program is planned to be completed on September 30, 1987. The estimated total cost of this three year program is $94M. Details of the schedule and cost are presented in Sections 6 and 7 respectively.

2. PHASE I OBJECTIVES

The SSC facility is to consist of a 20 TeV proton-proton collider, an injector complex producing beams for injection into the collider, and a campus-like arrangement of buildings providing office and laboratory space, shops and other support services. The scale and possible arrangement of these facilities are shown in Section 4. The primary accelerator design objectives for the SSC are given in Table 2-1.

Table 2-1

Primary SSC Design Objectives

Maximum proton beam energy (TeV/beam)	20
Maximum luminosity ($cm^{-2}sec^{-1}$)	10^{33}
Number of interaction regions	6

2.1 Overall Objectives. The major objectives of the SSC Phase I program are:

- To develop the performance specifications for the SSC consistent with the recommendations of HEPAP and its 1983 Subpanel on New Facilities with consideration of the results of subsequent pertinent studies and deliberations.
- To conduct SSC design and R&D activities, making use of the skills, experience and facilities of National Laboratories, Universities and the industrial sector.

- To select an optimum superconducting magnet design style for the SSC based upon technical, economic and operational criteria.
- To develop, as required for timely consideration in the FY88 budget process, the SSC Conceptual Design Report including costs, schedule, staffing plan, and other elements showing how the SSC can be realized in a practical, environmentally sensitive and safe manner.
- To evaluate site parameter requirements and to provide site information specification documents.
- To develop and demonstrate cost effective techniques for fabrication of magnets.
- To conduct systems tests to evaluate performance and reliability of magnets and other components.
- To conduct studies of the selected site and to provide design plans of early critical path structures following site selection.
- To develop a catalogue of operating needs for the SSC including utilities, cryogens, maintenance supplies, and manpower levels.
- To conduct appropriate R&D activities for the development of advanced particle detectors.

2.2 Technical Objectives. A major objective of the Accelerator Physics group is to obtain a detailed understanding of the beam dynamics of high current stored beams as prescribed for the SSC. These studies will provide input to the systems designers on such crucial issues as magnet aperture, field quality, and alignment tolerance requirements over the postulated operating range of the accelerator systems.

The Magnet R&D program will be geared to develop magnets that meet the aperture and field quality requirements necessary for the SSC. Additional objectives are to optimize technical performance and reduce costs of the final design, to develop and demonstrate the manufacturability of the magnets in a reliable and cost effective manner and to demonstrate the performance of systems of magnets.

R&D for other accelerator systems such as Refrigeration, Instrumentation and Controls, Power Supplies, Injector, Vacuum, RF and Abort Systems share the common objective of conducting sufficient studies, including modeling and some prototyping, to assure that cost effective and reliable systems are incorporated.

The objectives of the R&D effort under conventional construction are to find ways to minimize the cost of conventional construction, to develop SSC site requirements and to develop a site parameters document which will be used in the DOE site selection process. A site master plan will be developed together with studies of design approaches leading to an optimized construction schedule.

2.3 Conceptual Design Report and Other Documentation. The objectives are to develop a detailed conceptual design, a firm cost estimate, a staffing plan, a proposed construction plan and schedule. Other documentation will include draft environmental impact information, a Project Safety Analysis Report, and Quality Assurance/Quality Control requirements.

3. MANAGEMENT - ORGANIZATION

The programmatic responsibility for Phase I rests with the Division of High Energy Physics (DHEP) Office of High Energy and Nuclear Physics (HENP) in the Office of Energy Research (ER). Responsibility for contract administration and performance monitoring rests with a special SSC Office in the DOE Chicago Operations Office (CH). The contract for SSC Phase I is held by the Universities Research Association (URA), which has created a Board of Overseers to carry out its responsibility for Phase I management.

The Director of the Central Design Group who reports to the URA Board of Overseers has been delegated the authority and assigned the responsibility to organize, plan and accomplish the objectives of the SSC Phase I program. Work on tasks necessary to accomplish these objectives will be carried on by the CDG, by Laboratories and Universities across the United States and by appropriate elements of the industrial sector.

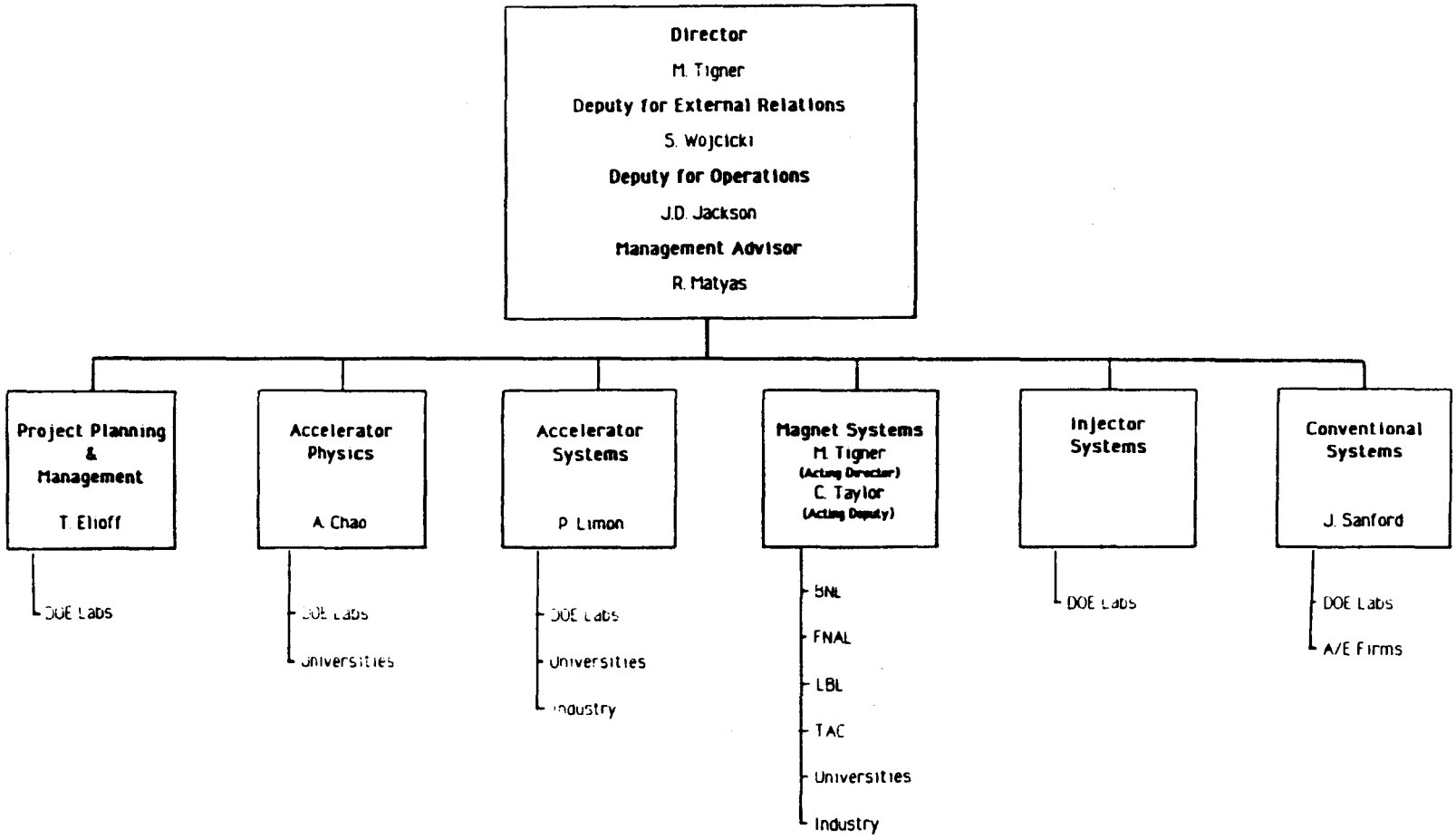
The Office of the Central Design Group has been located at the Lawrence Berkeley Laboratory. The address is:

Universities Research Association
SSC Design Center
c/o Lawrence Berkeley Laboratory
Mail Stop 90-4040
One Cyclotron Road
Berkeley, California 94720

The Organizational Chart for the CDG is shown in Figure 3-1. The Organization reflects the major SSC technical systems that will be involved in the Phase I program. Approximately 40 technical and support personnel are projected for the CDG organization in FY85.

While direction and coordination of the Phase I effort rests with the CDG, work will also be carried out under bilateral agreements and contracts between

FIGURE 3-1
PRELIMINARY SSC PHASE I ORGANIZATION



the CDG and various institutions, such as National Laboratories, Universities, Industrial and Architect-Engineering Firms. The CDG will be responsible for oversight, coordination, and integration of all SSC related activities. The CDG will develop a plan for industrial involvement in the SSC program at the earliest appropriate time, insuring that fair opportunities are provided to all interested and qualified parties.

Management and organizational considerations are provided in more detail in the SSC Phase I Management Plan.

4. SSC DESIGN CONCEPTS

A brief description of the planned SSC facility is provided below. This picture serves to indicate the nature of the required facilities and the scale of the accelerator systems; it does not represent a final or an optimized design.

The energy of the SSC (20 TeV per beam) and its high design luminosity (10^{33} $cm^2 sec^{-1}$) are a substantial extension of the major parameters of existing colliders, proposed or under construction. The SSC will be able to probe to a much higher mass scale or to smaller subnuclear distances than are accessible with any other existing or planned facility. It thus offers the scientific community the means for making major advances in our growing knowledge of the fundamental properties of matter and in our unified understanding of the forces of nature.

The main SSC technical components are a cascaded series of particle accelerators of increasing energy: 1.0 Gev Linac, 70 Gev Low Energy Booster, 1.0 Tev High Energy Booster, and the 20 Tev on 20 Tev proton-proton collider. A possible arrangement of these systems is shown to scale in the schemetic representation of Figure 4-1. The collider ring shown is 60 miles in circumference, representing one of the options currently under consideration. Figure 4-2 is a projected aerial view of the SSC complex on a median site.

The most visible parts of the SSC will be the office, laboratory and shop buildings in the central campus of the facility and the experimental buildings that will be located around the ring at the interaction regions. An advantageous place for the central campus is near the point of beam injection into the main ring as shown in Figure 4-3. The outline of the low energy booster ring is seen to the right of the building complex. Because the area

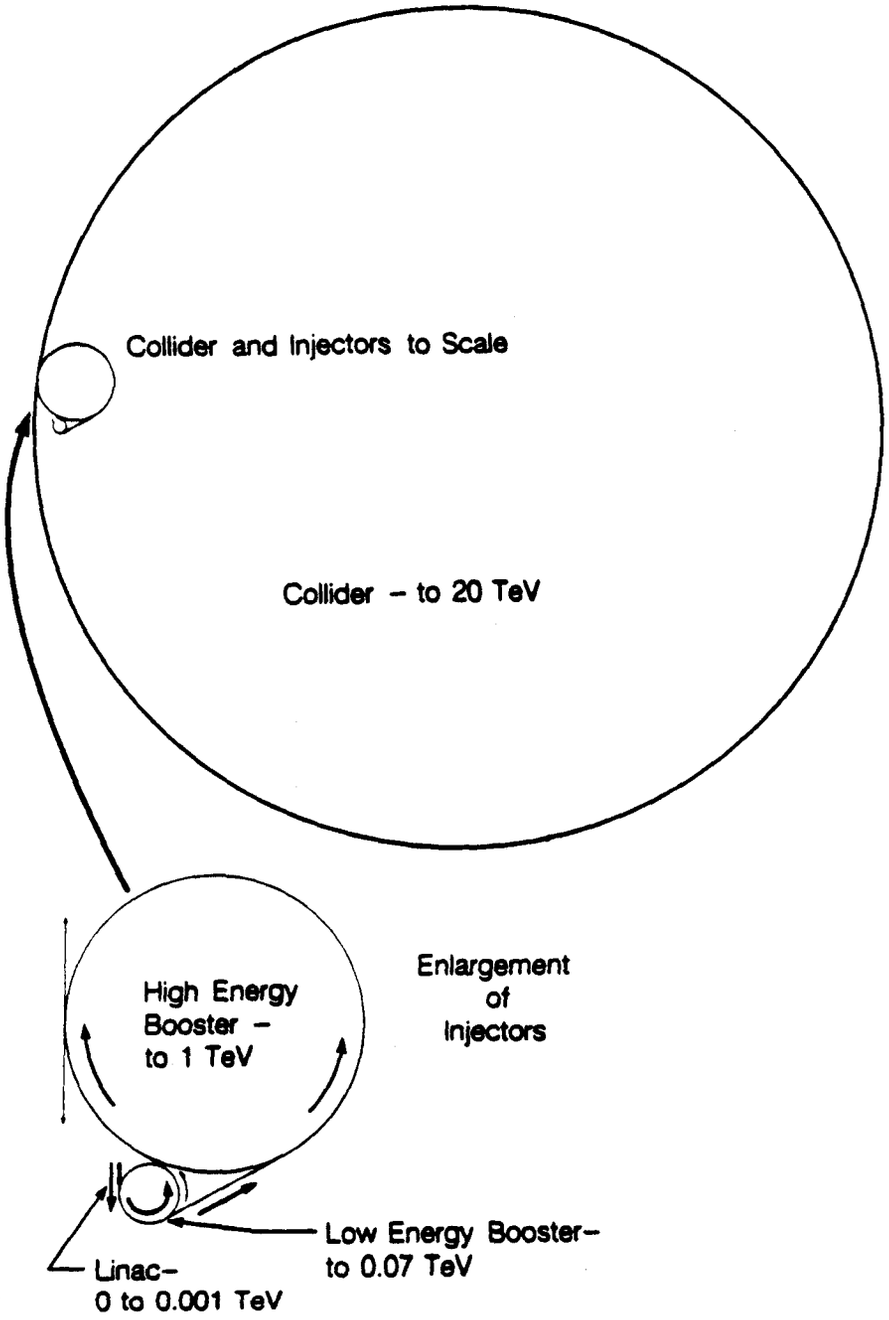


Figure 4.1 Layout of the SSC indicating the injector complex and the main ring where protons are accelerated to 20 TeV in counter-rotating bunches that collide at six points along the circumference.

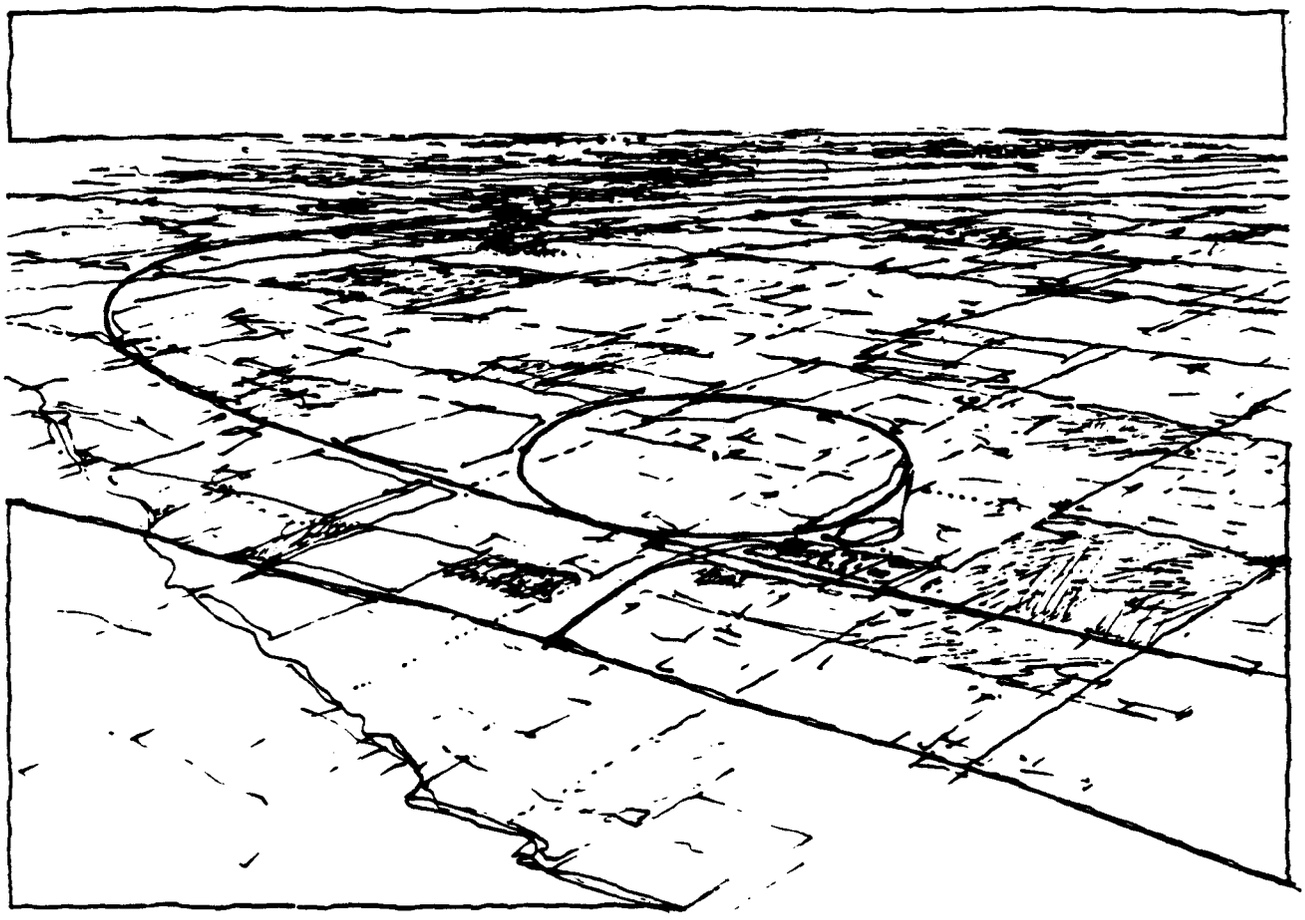


Figure 4.2 Aerial view of median site illustrating the scale of the SSC facility and the relatively unspoiled nature of the countryside once the machine is in operation. The main ring perimeter is only noticeable when the tunnel approaches the surface too closely. Buildings arranged in circular array near the campus outline the injector machine. The laboratory building and the campus-like assembly of industrial buildings are areas of major concentration and staff activity. Access roads to nearby population centers are clearly visible.

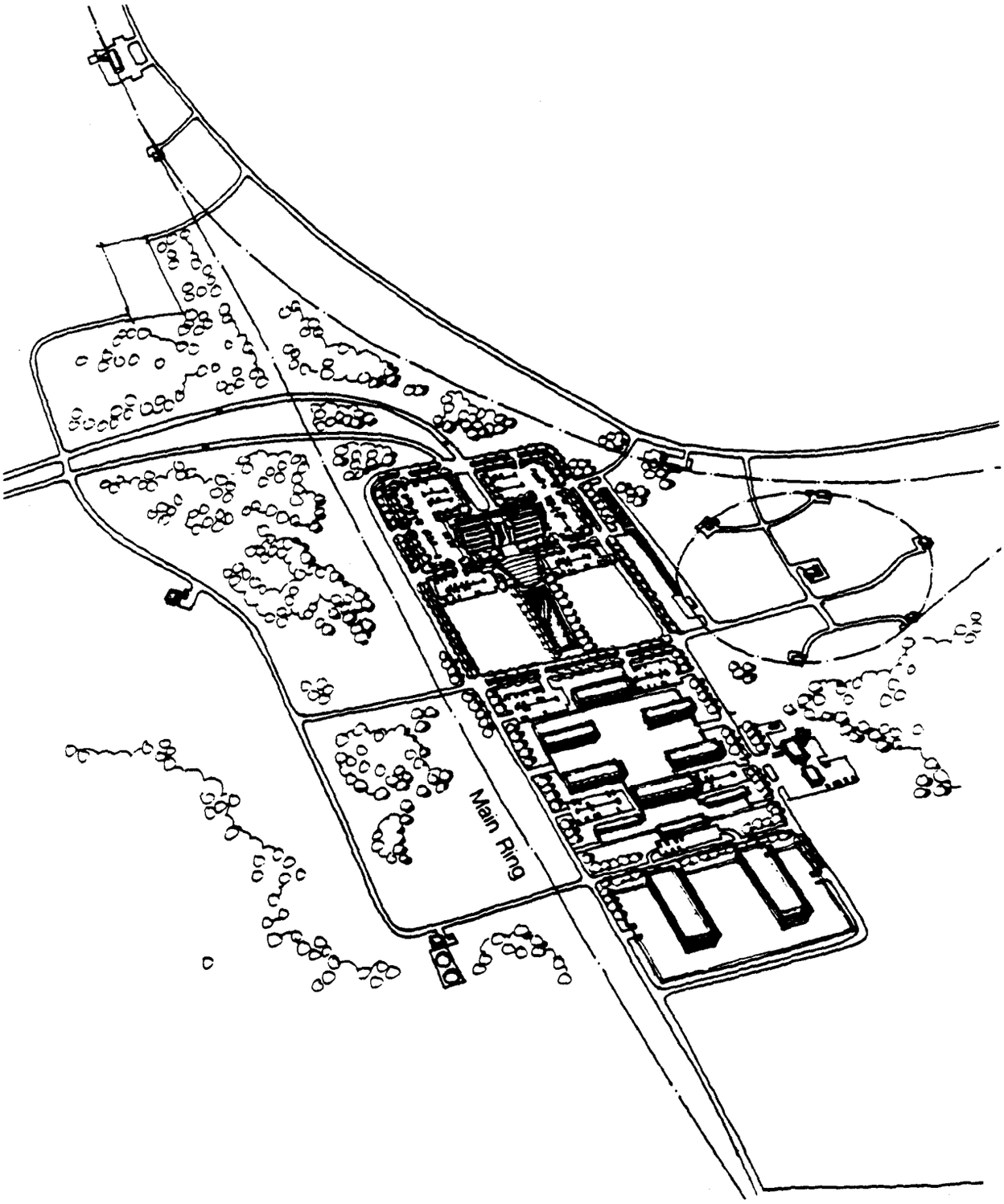


Figure 4.3 Aerial view of the campus revealing its compact arrangement and its proximity to the injector facility.

of the campus is very small in comparison with the size of the main ring, most of the surface area of the site will not be affected by the construction of the SSC.

The collider ring will be housed in a tunnel below ground where superconducting dipole and quadrupole magnets will steer and focus two counter rotating beams of protons in nearly circular paths. In most of the circumference the two beams travel in separate parallel vacuum enclosures. At 6 special locations around the circumference the beams are focused to transverse dimensions of a few microns and brought into near head-on collision. It is at these locations that complex experimental detectors will analyze the results of the collision process. Figure 4-4 shows a perspective view of the main ring tunnel and the vacuum pipe in which the magnet systems are enclosed. Figure 4-5 shows the superconducting magnet system within the vacuum pipe. Figure 4-6 and 4-7 provide similar views of other magnet system designs. These designs typify the range of options from which the final optimized design will be determined. Detailed descriptions of these systems can be found in the Reference Designs Study Report of May 8, 1984.

The next section of the Program Plan (Section 5) will describe the Research program for the technical development of superconducting magnet systems as well as other accelerator components.

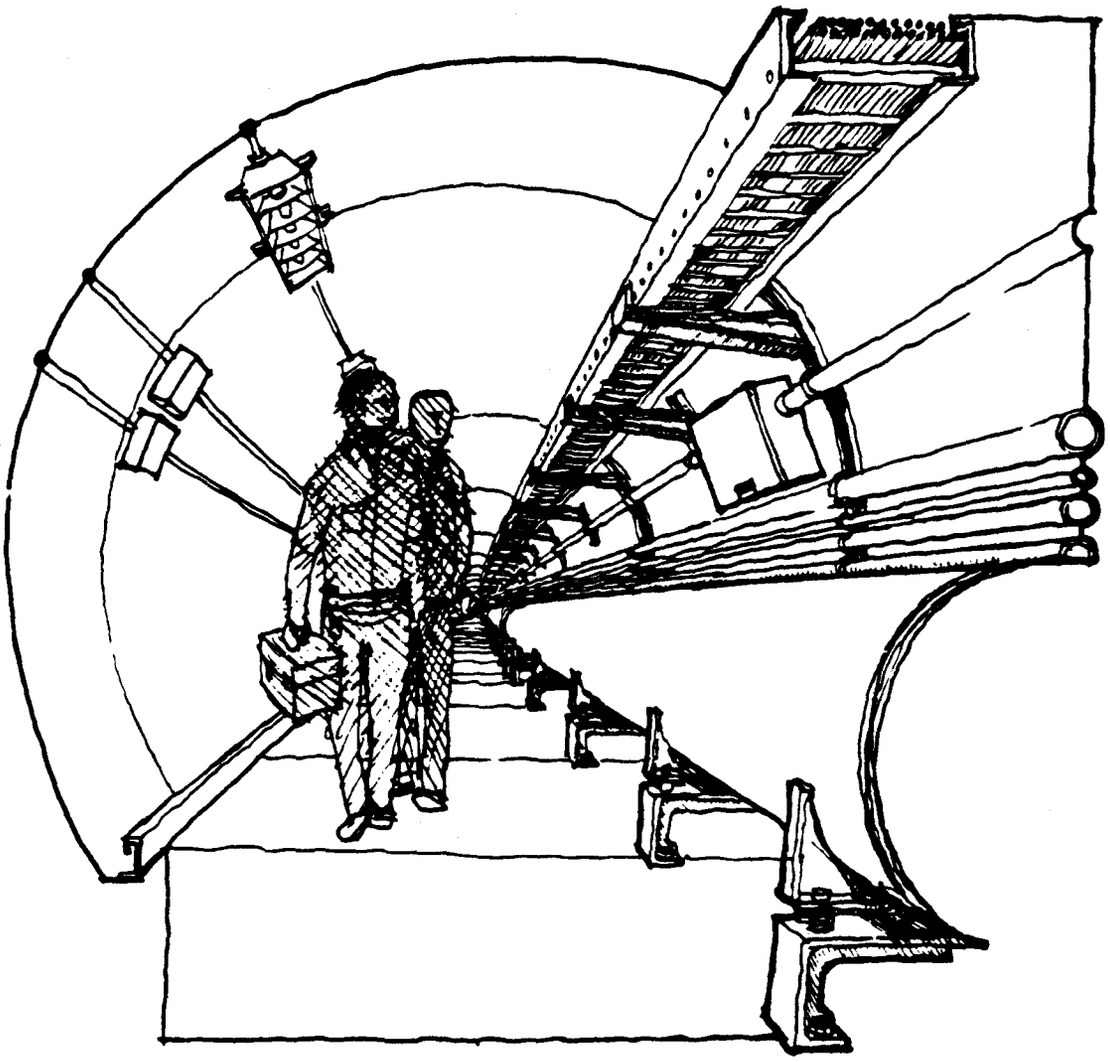


Figure 4.4 Perspective view of the main ring tunnel.

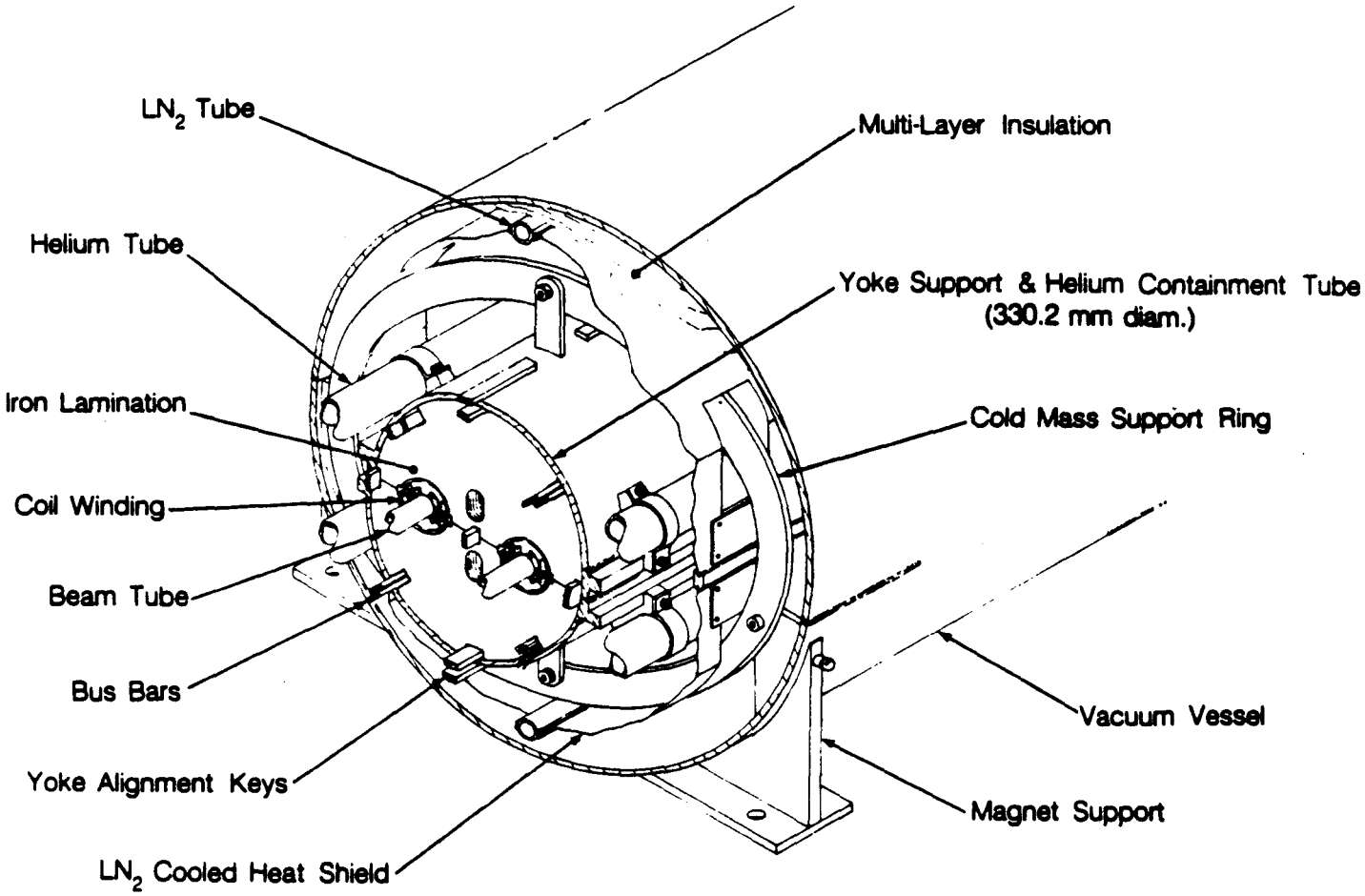


Figure 4.5 **Cutaway perspective view of the 6.5 T, 2-in-1 dipole magnet.**

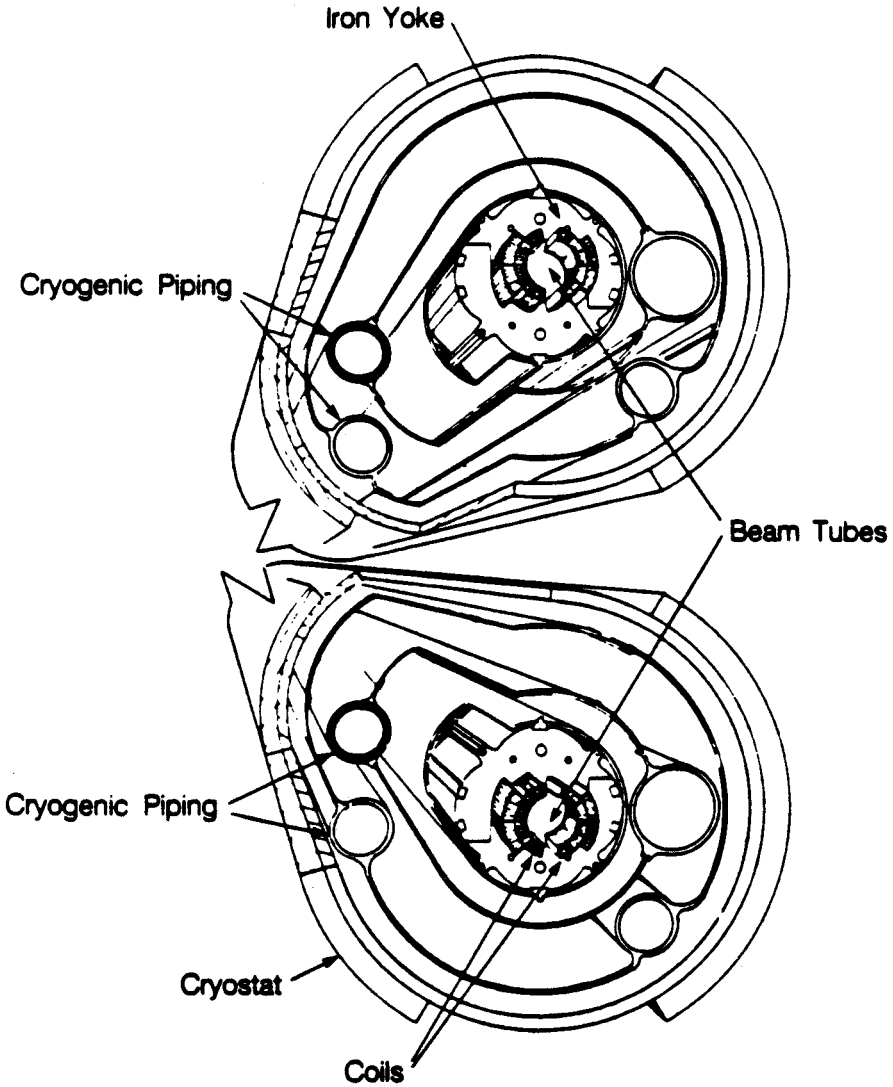


Figure 4.6 Cutaway perspective view of the 5 T, 1-in-1 dipole magnet.

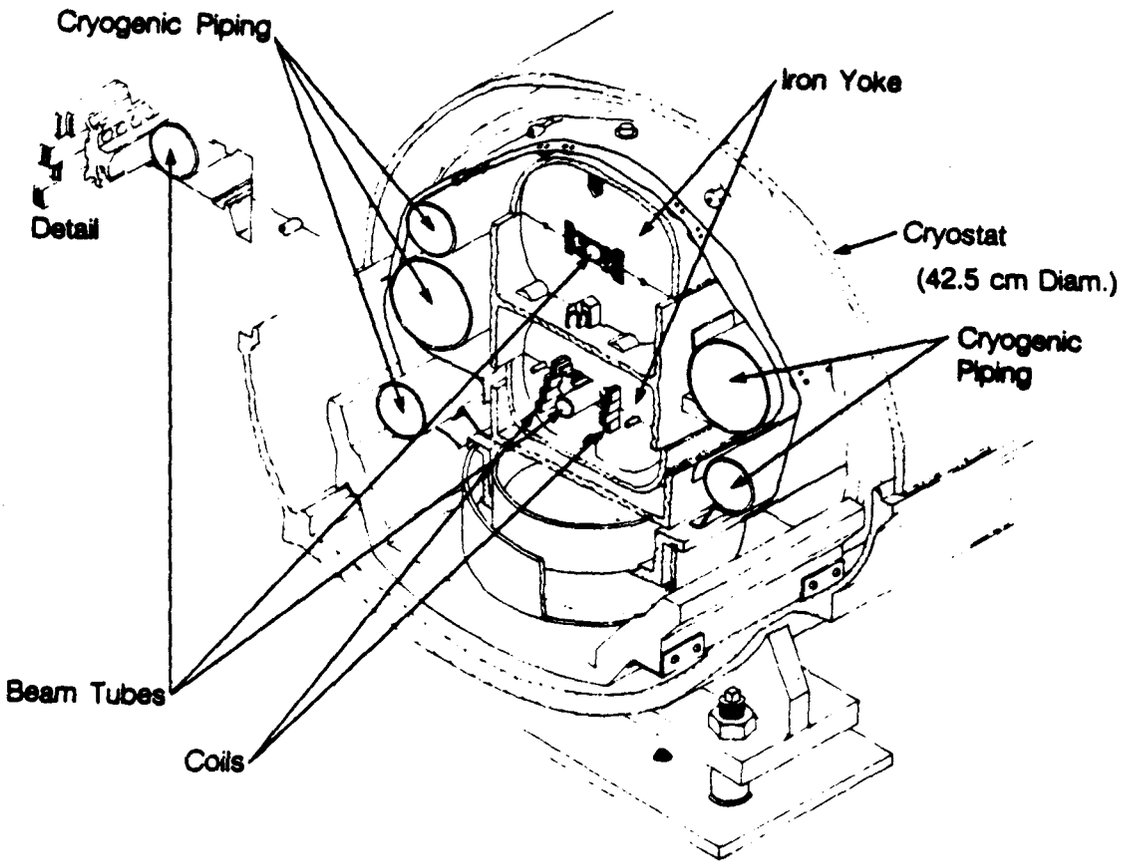


Figure 4.7. Cutaway perspective view of the 3 T, superferric dipole magnet.

5. PROGRAM DESCRIPTION

5.1 Development of Program Tasks

The Reference Design Study Report of May 1984 served to provide a systematic identification of many R&D Tasks that are associated with each technical system of the SSC. Additional tasks have been identified in subsequent reviews and studies by the CDG. Examples of such studies are the Magnet Systems Test Site Task Force, the Magnet Aperture Workshop, the Managerial & Fiscal Panel for the SSC Magnet Program, and the SSC Technical Magnet Review Panel. The results are summarized in Appendix A which represents a comprehensive list of tasks, issues, studies, and problems that must be addressed during Phase I. The Work Breakdown Structure (WBS) for the Phase I program (see Table 5-1) is designed to incorporate these tasks appropriately into the SSC organizational structure.

The studies noted above clearly indicate two important areas of the R&D program which are on the early critical path for accomplishing the program goals. These areas are the R&D activities required to provide input for magnet selection and the site criteria development program which is the first step in the extensive process of site determination. A major part of the R&D effort for FY85 is therefore directed toward accomplishing the tasks related to these areas.

TABLE 5-1

WORK BREAKDOWN STRUCTURE

X. SSC Phase I Program

1.0 Central Design Group

1.1 Administration
- 1.1.1 Director's Office
- 1.1.2 Administrative Support

1.2 Program Planning and Management

1.3 Accelerator Research and Development
- 1.3.1 General
- 1.3.2 Accelerator Physics
- 1.3.3 Accelerator Systems
- 1.3.4 Superconducting Magnets
- 1.3.5 Injection Systems

1.4 Conventional Systems
- 1.4.1 Planning and Coordination
- 1.4.2 Site Parameters
- 1.4.3 Conceptual Design
- 1.4.4 Special Studies

2.0 Brookhaven National Laboratory

2.1 General
2.2 Magnet Models
2.3 Tooling
2.4 Magnet Measurements
* 2.5 Power Supplies and Quench Protection
* 2.6 Cryogenic System

TABLE 5-1 (Continued)

3.0 Fermi National Accelerator Laboratory

- 3.1 General
- 3.2 Magnet Models
- 3.3 Facility Development and Operation
- * 3.4 Superconductor Development
- * 3.5 Cryostat Development
- * 3.6 Accelerator Physics

4.0 Lawrence Berkeley Laboratory

- 4.1 General
- 4.2 Model Magnets
- 4.3 Calculations and Analysis
- 4.4 Instrumentation and Measurements
- * 4.5 Accelerator Theory
- * 4.6 Superconductor Development

5.0 Texas Accelerator Center

- 5.1 General
- 5.2 Short Magnet Model
- 5.3 Long Magnet Models
- 5.4 Tooling Development
- 5.5 Theoretical/Analysis
- 5.6 Facility Development

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*Ongoing Laboratory Accelerator R&D activities that are relevant to the SSC program.

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5.2 The FY85 PLAN

5.2.1 Program Summary. The major areas of research for the FY85 program are Superconducting Magnet Development with related Accelerator Physics Studies and Site parameters Development.

A primary goal of the accelerator physics studies is to determine an optimized storage ring lattice that ensures achievement of design luminosity at each interaction point with a minimum intensity of stored beam. The lattice design will be translated into the specifications for magnet systems in terms of field quality and aperture. At the same time several different magnet design concepts are being investigated. This magnet development program is geared to provide critical input for the selection of a single magnet style in FY85.

Currently short magnet models are being produced and tested. These models will focus on providing information for aperture and field quality evaluation. This program also addresses issues of design and fabrication techniques which are aimed at maximum reliability and cost effectiveness for operations and minimum costs for production. In parallel with this effort is a program to develop outside industrial capability for the production of uniform, reliable, and improved high-field NbTi superconducting wire and cable. The development of engineering

designs and tooling necessary to produce magnets economically and reliably is also being pursued. Following selection of the magnet style and the development of satisfactory magnet models and prototype tooling, full-scale prototype magnets and associated cryogenic hardware will be fabricated. Of particular importance will be measurement and minimization of the cryogenic system heat leak. The envisioned cryogenic systems are strongly dependent on achieving a very low level of heat leak.

With regard to conventional systems, the development of site criteria and a detailed catalogue of information needed for the DOE site selection process is on the critical path and must be actively pursued. Thereafter the overall design and development of conventional systems will be accomplished in concert with the technical systems requirements in order to provide a complete SSC Conceptual Design.

5.2.2 Superconducting Magnet Program. The primary objectives of the FY85 program are the selection of a Basic Magnet Type and the development of a final engineering design for Magnets of the chosen type. Selection of a basic magnet design type with which to proceed should be based on three major considerations: operational characteristics, potential reliability and cost. Development of the working engineering

designs will include many elements such as model tests of various possible design features and studies of tooling and manufacturing methods. These two major program components are intertwined to a considerable degree. To be successful such a program must draw on the collective resources of the community in many areas.

The SSC Magnet Program involves R&D Groups at BNL, LBL, FNAL, & TAC. These groups strongly interact with the CDG via technical input for magnets and magnet systems. Industrial consultants are used both by the CDG and through the laboratory groups. The CDG also utilizes a Technical Magnet Review Panel for advice on technical issues. The membership is drawn from the national pool of superconducting magnet experts.

Reviews and assessments of special technical or operational features are necessary for successful design of the SSC. Accordingly a number of panels and task forces composed of experts from the US and abroad have been formed. These include:

- Technical Magnet Review Panel
- Stability Assurance Task Force
- Photodesorption Task Force
- Aperture Task Force
- Operational Factors Task Force
- Reliability Assessment Task Force
- Cost Estimating Task Force

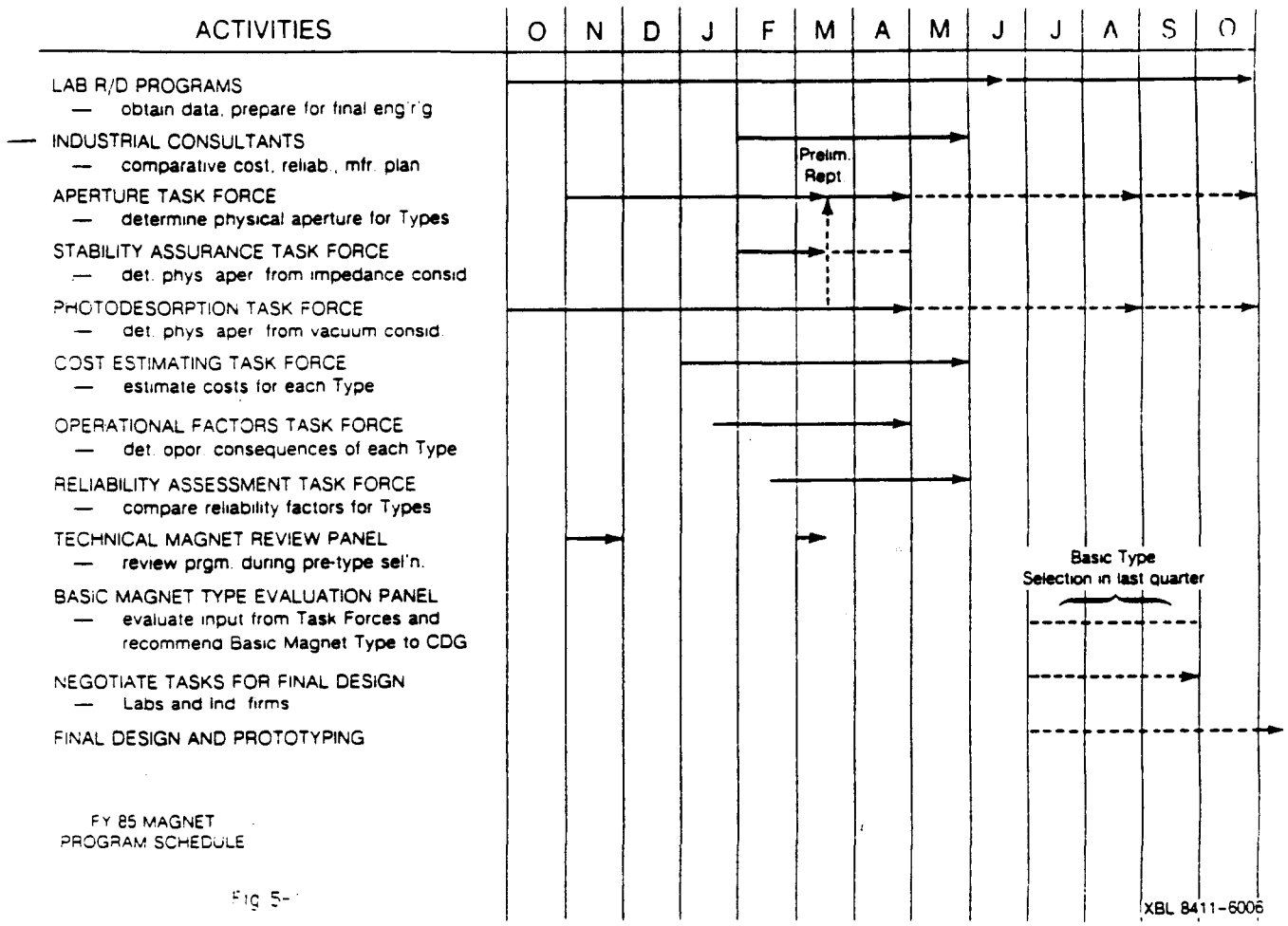
All of the information resulting from these Panels and Task Forces will be utilized by the CDG through a Basic Magnet Type Evaluation Panel to determine the optimum design style for the SSC Magnet System. Following this determination, the CDG will formulate an integrated program to move forward with the final engineering and design. This program will use the resources and technical abilities of the various DOE Laboratory R&D groups as well as industry.

Figure 5-1 shows the time scale for the activities of the Task Forces, consultants, and review panels during FY85. The selection of a Basic Superconducting Magnet Type will occur in the last quarter of FY85.

There are a number of basic magnet types under consideration which one can parameterize as shown in Table 5-2. The systems checked show which Basic Magnet Types are now receiving most attention and at which institution it is being investigated. The systems bearing an X mark Basic Magnet Types known to be uneconomical.

FIGURE 5-1

FY 85 MAGNET PROGRAM SCHEDULE



FY 85 MAGNET PROGRAM SCHEDULE

Fig 5-1

TABLE 5-2

BASIC MAGNET TYPES

	"2 in 1" Magnets	"1 in 1" Magnets
Lo B Cold Fe	✓ TAC	✓ TAC
Hi B Cold Fe	✓ LBL BNL FNAL	✓ LBL BNL FNAL
Lo B No Fe	X	X
Hi B No Fe	X	✓ FNAL

Notes to Table:

1. In this context Lo B refers to fields of about 3 Tesla and Hi B to about 6 Tesla.
2. "2 in 1" references to mechanical and cryogenic linkage of the two SSC beam channels. In the Hi B case the channels have strong magnetic linkage.
3. Most design consideration is now being given to magnets based on the well established NbTi cable technology. The current density capability of this technology is continually improving.

The process for selecting the Basic Magnet Type is comprised of several components, namely data acquisition, data analysis, evaluation and final selection. Each component will depend on input from the community of experts and active participants in the development of superconducting magnets for accelerator service. The input data and some analytical work will be acquired from the ongoing R&D programs at Laboratories and universities, from studies by industrial consultants commissioned by R&D performers and by the CDG, from Task Forces and Workshops convened for the purpose, and by the CDG itself. During the pre-selection period the CDG will be advised in review and evaluation by a Technical Magnet Review Panel comprised of recognized experts and leaders in the superconducting accelerator magnet area. In making the final Basic Magnet Type selection, the CDG will be advised by a Basic Magnet Type Evaluation Panel, appointed by the CDG, and similar in composition to the Technical Magnet Review Panel. This panel will be supplemented by accelerator magnet experts from abroad and with additional members from industry and system disciplines.

The Basic Magnet Type Evaluation Panel will make its evaluations and recommendation based on consideration of the three major areas concerning each of the Basic Magnet Types being assessed: operational characteristics, potential reliability and cost.

With regard to operational characteristics each of the Basic Magnet Types have inherent features, as opposed to detailed design features, affecting operational performance of a complete collider system based on that Basic Magnet Type. High operational duty factor at the needed operating parameters of energy and luminosity is a primary consideration for the SSC. In addition to the effective operation at collision energy with good beam control and minimum incidental background for the detectors, other factors such as efficient injection, stacking and acceleration will be important. Delineation and evaluation of operational performance characteristics will involve considerations of:

- lattice restrictions
- cryogenic coupling between beam channels
- electro-magnetic coupling between beam channels both in the bending dipoles and focusing magnets
- correctability of placement and field errors
- unwanted multipole components
- cool-down and warm-up time
- quench protection
- quench recovery time

There are two major aspects of potential reliability for magnet systems which merit evaluation: the reliability of the individual magnets as components and the reliability of a

complete system of magnets. For component reliability one must evaluate characteristic tolerances, number of units, mechanical and electrical stress, and complexity such as the number of parts and welded joints. For systems reliability the factors for consideration involve mechanical supports, refrigeration, correction elements, quench protection, and overall monitoring and controls.

Magnet Cost Analysis requires evaluation of both capital costs and operation costs. The capital costs will be determined from the specific elements of the design including the materials, fabrication methods, and assembly and testing techniques. The operational costs will depend on total heat load, convolution of warm-up/cool-down costs with expected cycle frequency, and the size and number of refrigeration units.

The above factors are pertinent to the selection of a magnet design style. After this selection process, efforts at the CDG and participating laboratories will focus on the final engineering design which will draw upon the information that has been assembled from the R&D programs. An important part of this effort will be a system test of the final magnet design. The magnitude of this effort requires early detailed planning. A Task Force on the Magnet Systems Test Site was appointed by the CDG director in August 1984 and is described further in Section 5.2.4.

The basic information that will be used in the assessment of operational characteristics, reliability and costs for different magnet designs is a product of the current R&D programs at BNL, LBL, FNAL, & TAC. The Basic Magnet Types involved in these programs are Superferric (TAC), No Iron (FNAL), Cold Iron 1-in-1 (LBL), and Cold Iron 2-in-1 (BNL). In addition BNL, LBL, and FNAL are collaborating on the development of a high field (6T) cold iron design. The basic elements of the associated R&D programs are described below.

The program at LBL can be divided into four components; Cable and Superconductor Development, Design-Engineering, Experimental Operations, and Model Magnet R&D. The Cable and Superconductor Program is aimed at optimizing the NbTi alloy composition and heat treatment in the billeting and at developing an industrial capability to draw fine filament-high current capacity superconducting wire. Techniques are also being studied to form the superconductor wire into quality cable (high compaction without degradation). The question of degradation during keystoning is also being investigated. The objective is to develop a mechanically improved cable.

The LBL Design Engineering effort involves design of magnet coil windings, design and mechanical (stress) measurements on prototype collars for clamping and pre-stressing coils and preliminary analysis and design of quadruples, correction

magnets and special intersection region bending and focusing magnets. In addition LBL will collaborate with industry in preliminary analysis and design of a complete magnet-cryostat system, including mechanical supports, vacuum vessel, heat-leak, cool-down and warm-up, helium piping requirements, construction tolerance requirements, and cost.

Experimental Operations for this program involves the performance of tests on one meter model magnets for such factors as stability (training), ramp sensitivity, quench characteristics, and field quality. These operations will involve the maintenance and operation of magnet test facilities and a wire and cable "short sample" test facility. The Model Magnet R&D involves the development of a detailed design for dipole magnet ends, evaluation of cable insulation, development of winding and molding procedures for the coils and the construction and testing of a series of one-meter model magnets.

The program at BNL involves the development of 4.5 meter magnets with emphasis on 3.2 cm and 4.0 cm bore magnets having stainless steel collared coils in a 1-in-1 and 2-in-1 cold iron yoke. This work can be divided into two components: Tooling and Test Equipment Design and Development; and Magnet Production and Testing.

The Tooling and Test Equipment Design and Development program involves the development of mandrels, a curing press, and a long winder for coil production; the development of the horizontal test facility tooling and measuring device; the development of collars and a modified press for prestress collar fittings; and the development of trim coil tooling.

The Magnet Production program involves a technique where superconducting cable is wound on 4.5 meter long mandrels, cured, clamped in stainless steel collars, and fitted into bolted iron yokes. The plan calls for four of these magnets to be build and tested in FY 1985.

The Magnet Testing program will include tests of peak field performance, magnetic field multipole content, persistent current effects, quench propagation velocity, temperature attained during quench, and trim coil performance.

The program at FNAL is concentrating on the development of a magnet system based on collared cosine theta coils similar to the FNAL saver design, but with reduced aperture, improved superconductor, increased length and reduced heat leak. The effort in FY 1985 will concentrate on Superconductor improvement (in close collaboration with LBL and BNL),

development and test of a "Dry-Wound" coil insulation system, cryostat and suspension development, and improvements to the Magnet Test Facility for magnetic measurements.

In the superconductor development, FNAL is exploring the development of strands with fine (5-6 micron) filaments. A passive superconductor scheme for correcting persistent sextuple fields is being developed.

The magnet program calls for development and design of dry winding techniques, study of collaring forces, and investigation of quench protection techniques. Both warm and cold testing will be performed to measure harmonics, training, quench protection, and multipoles. Persistent current sextuple measurement and correction will also be studied.

A long vacuum vessel will be built to develop supports and alignment techniques. Testing will include cool-down, heat leak measurement, quench protection, magnet performance, electromechanical interactions, field quality, and life tests. Emphasis will be put on the design of a cryostat for Cosine Theta Type Magnets.

<u>The program at TAC</u> is aimed at developing a low (3T) field, 2-in-1, cold iron magnet system for the SSC. The design is an iron dominated magnet with aperture of approximately one inch. The plans for FY 1985 call for the building and testing

of several short (3 foot) models, and several longer (25 foot) models. Full length models (92 ft.) are also planned. TAC will use superconductor from the LBL/BNL/FNAL development programs in their cabling process. Some magnets will be tested at BNL.

The purpose of the three foot models is to study mechanical and magnetic consistency. The 25 foot models will be built to study techniques for building longer magnets, to test magnet alignment, to develop cryostats and to check heat leak. The long magnet (92 ft) program is planned to study length and mechanical characteristics, and shipping and testing techniques. The TAC program plans to involve industry in the fabrication of the 92 ft. models.

The schedules for fabrication and testing of magnet models for the programs described above are presented in Figures 5-2, 5-3, 5-4 and 5-5.

FIGURE 5-2

BNL MODEL MAGNET SCHEDULE

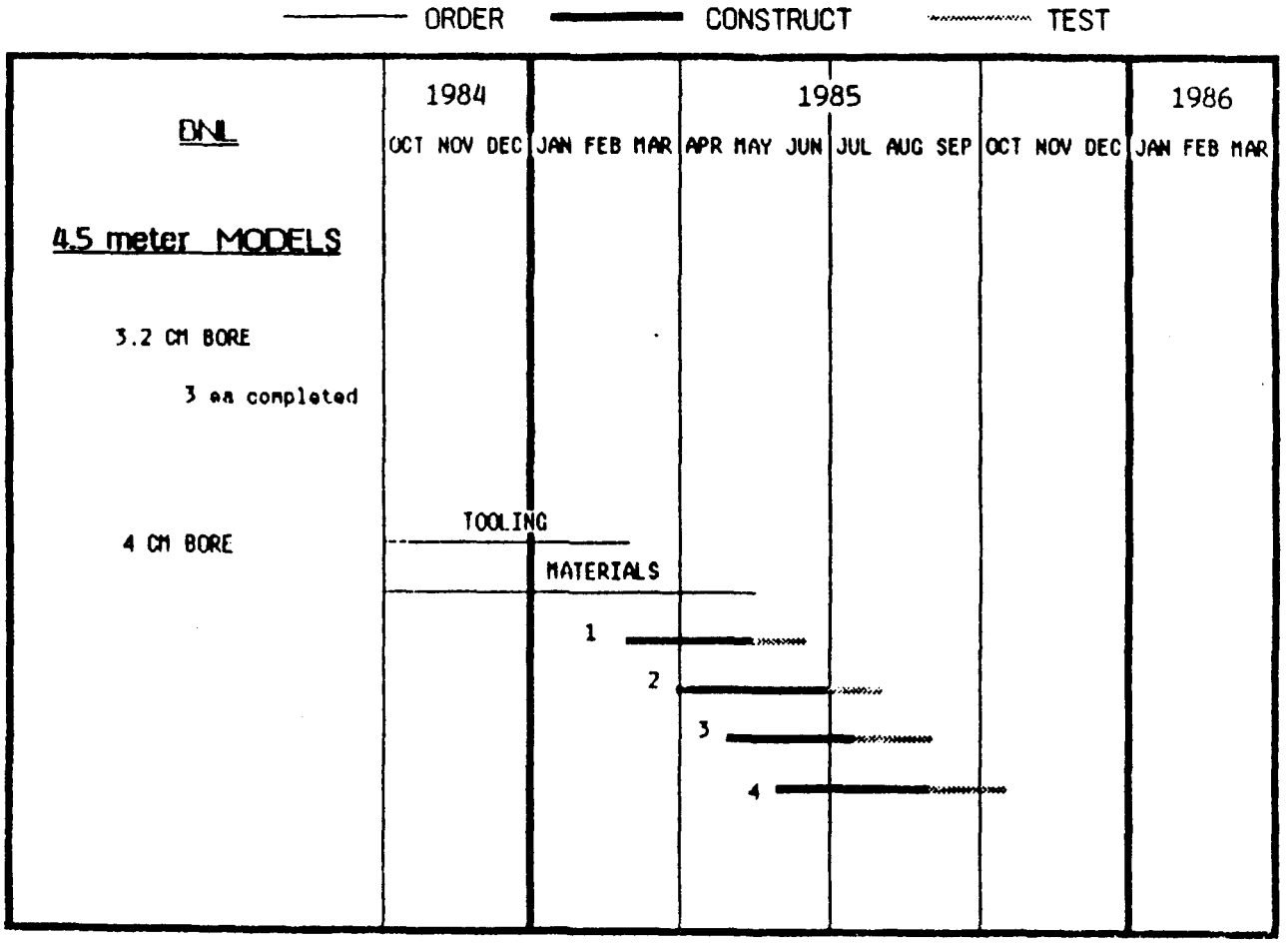
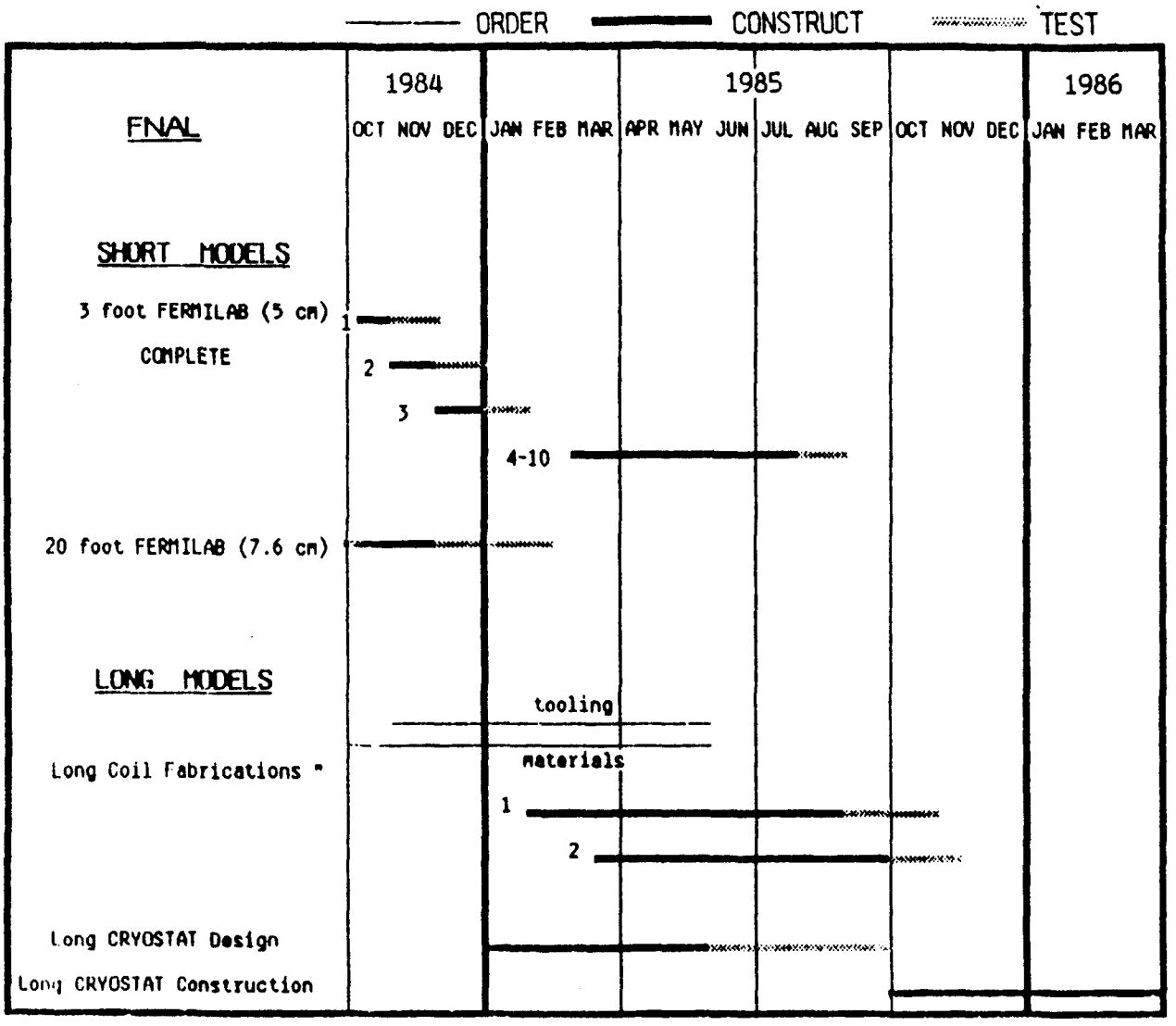


FIGURE 5-3

FNAL MODEL MAGNET SCHEDULE



*Pending Successful Development of Dry Winding Techniques

FIGURE 5-4

LBL MODEL MAGNET SCHEDULE

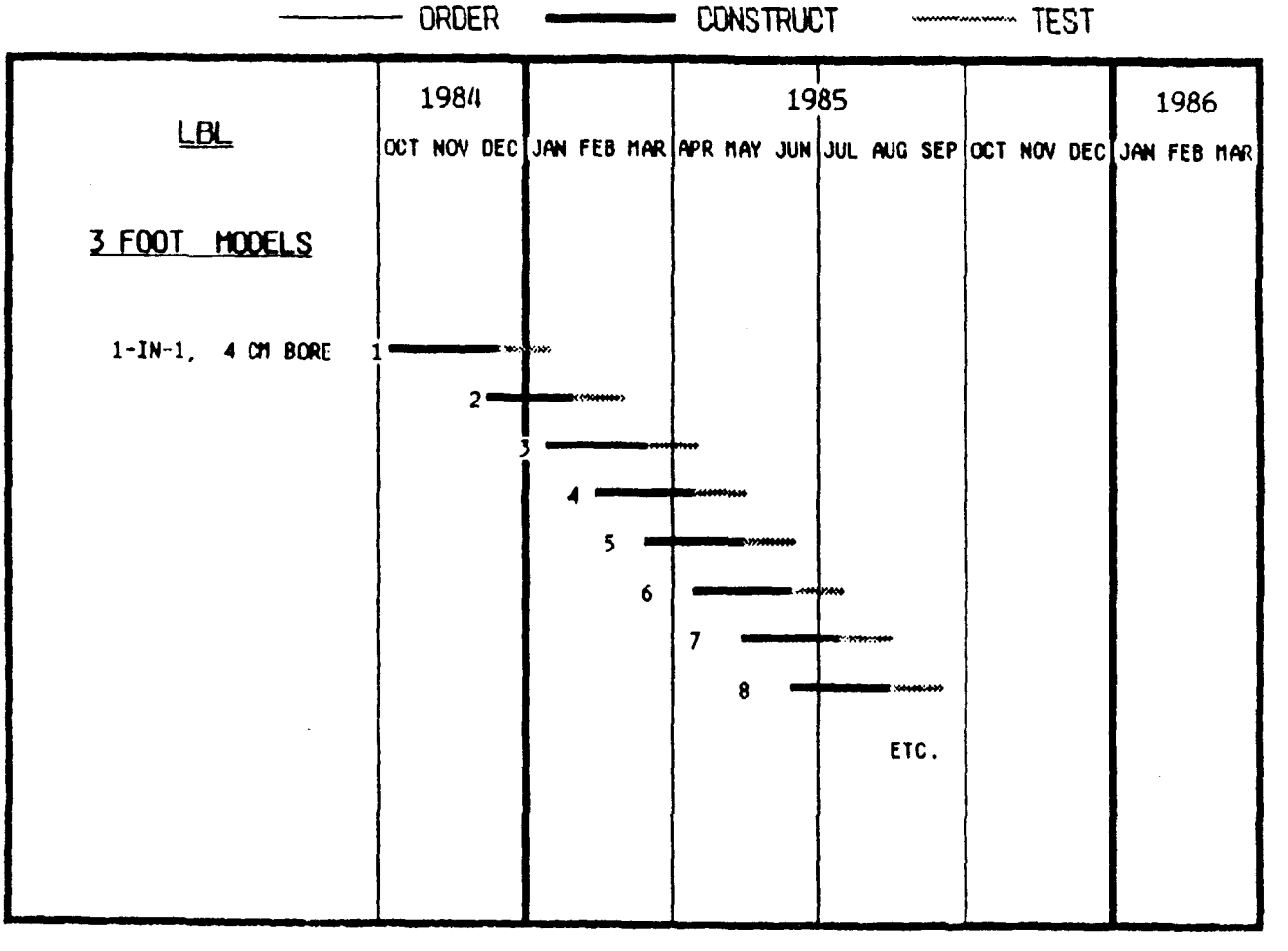
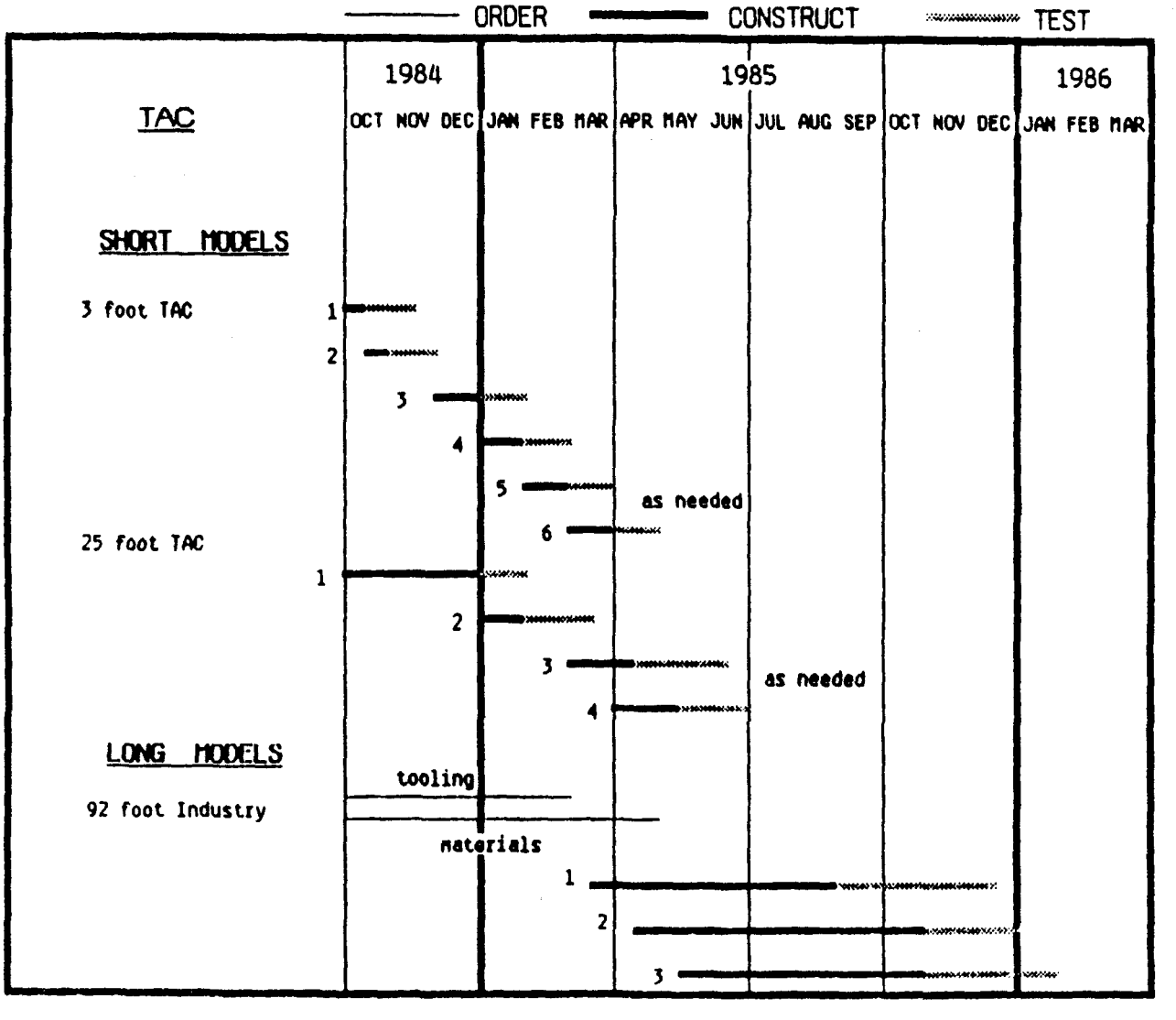


FIGURE 5-5

TAC MODEL MAGNET SCHEDULE



Magnet Engineering Design. The information from the current programs will be used for the magnet type selection process and it will also provide the technical basis for the development of the final magnet design. It is envisioned that a widely based, collaborative effort, employing the particular resources and strengths of the labs and institutions now involved, will be needed in this development.

As soon as practical after the Basic Magnet Type Selection, task assignments for final development of the chosen magnet type will be made. Proposals from the laboratories and institutions wishing to participate will be invited. Invitations to submit proposals will be issued at about the time of Basic Magnet Type Selection by the CDG. A plan for industrial involvement in the early stages of final design and prototype development will be prepared prior to this time.

R&D results germane to efficient production of magnets, such as tooling and manufacturing plans, fast coil winding methods, effective cabling methods, and all inclusive cable specifications, as well as research on long cryostat designs including mock-up measurement and design of support and alignment systems, will be valuable as input to the final engineering design.

5.2.3 Conventional Systems Program. In concert with the technical activities described above, the scheduled SSC milestones require an active effort for conventional systems. An important milestone for April 1985 is the Site Parameters Document. A considerable effort will be required in the preparation of this document. A summary of the near-term tasks is as follows:

a) Preparation of a Site Parameters Document that would indicate the information required for potential sites.
b) Guidance for the preparation of preliminary environmental impact statements and safety analysis reports.
c) Preparation of designs for conventional systems on a representative site, to be part of the Conceptual Design Report.

In order to accomplish the prescribed tasks, the services of an Architectural and Engineering Firm (A/E) are planned for early 1985. The A/E will assist the CDG in the study of site requirements and data relevant to site selection. The parameters expected to be important for selection of a site suitable for the SSC will be defined. An example of such parameters to be included in this evaluation is shown in Table 5-3.

TABLE 5-3
SSC SITE SELECTION INFORMATION TOPICS

A. GENERAL LAND DESCRIPTION
   1. Land usage
   2. Configuration
   3. Natural features
   4. Manmade features
B. CLIMATE
   1. Temperature and humidity
   2. Precipitation
   3. Wind conditions
   4. Storm history
   5. Solar energy
C. GEO-TECHNICAL
   1. Topography
   2. Soil properties
   3. Geology
   4. Hydrology
   5. Corrosion
D. UTILITIES
   1. Electric power
   2. Fuel sources
   3. Telecommunication
   4. Water
   5. Waste disposal
E. ACCESSIBILITY
   1. Population
   2. Airports
   3. Interstate highways
   4. State/local roads
   5. Railroad
   6. Public transportation
F. SURROUNDINGS
   1. Human resources
   2. Housing
   3. Industrial base
   4. Universities/colleges
   5. Cultural resources
   6. Community support
G. ENVIRONMENTAL
   1. Ecological description
   2. Baseline data
   3. Archeological record
   4. Historical landmarks
H. SAFETY CONSIDERATIONS
   1. Life support
   2. Safety requirements
   3. Local codes
I. LAWS AND REGULATIONS
   1. Land use policies
   2. Zoning
   3. Rights of way
   4. Labor laws
   5. Tax consequences

Guidelines within the site criteria document will provide available site related information including required area, size, capacity or other parameters required for the SSC. Siting criteria will be developed and reviewed by the Central Design Group and Department of Energy (DOE) staff and will be input for the Request for Proposal (RFP) in soliciting candidate sites.

A Generic Environmental Impact Statement (GEIS) will be prepared. The GEIS is a useful tool in the environmental assessment of broad-based actions or related groups of actions that agencies are likely to approve, fund or directly undertake. The GEIS differs from the site specific EIS by being more general or conceptual in nature. For the SSC Project, the GEIS will set forth conditions, criteria or thresholds under which the site specific Draft EIS's will be prepared. The site criteria identified above will be used in preparation of the GEIS.

In addition to site related issues, consideration must be given in FY85 to the methods for providing appropriate beam housing (tunnel enclosures) for the accelerator systems. The Reference Design Study showed that the collider tunnel and its surface penetrations constitute a large fraction of the total SSC cost. Accordingly an SSC Tunnel Technology Review Panel of recognized experts in this field has been formed to advise the

CDG as to R&D directions appropriate to possible reductions of tunnel construction costs. Studies in this area are anticipated in FY85.

An important issue related to accelerator operations in tunnel enclosures is that of personnel safety during operations of large cryogenic systems. Studies involving tunnel experts, cryogenic engineers, and physicists expert in safety matters will be undertaken.

5.2.4 Central Design Group Program. The CDG has the responsibility for organizing, planning and coordinating all Research & Development for the SSC Phase I program. Efforts for the magnet program in FY85 will involve largely the coordination of programs at existing laboratories together with the detailed planning for the selection of a magnet style. In the area of accelerator physics studies, the CDG staff will play a central role with assistance of personnel from other institutions.

The main task of the accelerator physic effort is to provide an optimized lattice (arrangement of deflecting and focusing magnets) that will contain the SSC stored beam in a manner that will ensure the design luminosity and will provide optimum performance for experiments. The required field quality and aperture of magnet elements will be established using

analytical methods, computer tracking programs, and where possible, experiments on existing accelerators. The maximum allowed magnet multipole errors will be determined together with orbit correction schemes and an understanding of potential misalignment errors. Also a program for the scaling of field quality with aperture will be developed in order to provide flexibility for the magnet designers and more accurate comparative cost estimates.

These investigations will include techniques for maintaining small emittance, the determination of the effects of RF noise, and the growth time of various beam instabilities. In order to maintain the quality of high current stored beams, the potential for beam instabilities must be fully understood and methods prescribed for their elimination or control.

An Aperture Workshop conducted in November 1984 involved 40 accelerator physicists from throughout the U.S.and Europe. The workshop served to identify the accelerator physics issues relevant to aperture determination as well as a plan for continued studies during FY85. Part of the plan calls for improving the calculational tools. Various computer analysis codes are being updated. More effective organization and coordination will be required of relevant computer codes to perform the many consecutive calculations, involving a large number of inter-related parameters, that are required in the

lattice optimization. Orbit tracking programs are being improved to involve high order systematic and random multipoles as well as survey and excitation errors. Many existing programs are now being prepared for utilization on the CRAY computer system at LLNL for improved speed and efficiency. With these enhanced calculational tools, an active program will be pursued in the first half of FY85 that will provide a theoretical prescription for the design aperture.

One of the most important goals of the FY85 program is the selection of a magnet style for the SSC. While the information from existing programs is of prime importance, the selection process, which is aimed at the optimum cost-effective design for the SSC, may determine a style which is somewhat different from the specific current designs. In guiding the magnet development process the CDG will involve Task Forces or Review Panels in the following areas:

Cost Estimating

Magnet Systems Operations

Aperture Requirements

Photodesorption Effects

Vacuum Envelope Impedance

Tunneling Methods

Magnet Systems Test Facility (String Test)

One of the first of these studies has involved the SSC Magnet Technical Review Panel. This 12 member panel was appointed by the SSC Director on October 8, 1984. This panel is charged to provide a technical review of each of the ongoing superconducting magnet R&D programs, to summarize the progress in FY84, review plans for FY85, and to make suggestions for enhancing the programs to meet the objective of making a magnet style selection at the earliest practical date.

The Magnet Technical Review panel met five times during October and November at the Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (FNAL), Lawrence Berkeley Laboratory (LBL), and the Texas Accelerator Center (TAC). Details for each program may be found in the report of this Panel. An important result of the panels' deliberations was to arrive at a preliminary basis for magnet style selection which would, in turn, help guide the R&D programs. The panel has suggested that this process be based on the following selection factors:

1. Measured magnet performance from tests of models relative to:
   (a) Reliability
   (b) Field quality
   (c) Reproducibility of design (considering required tolerances and planned manufacturing processes)
   (d) Quench behavior, training experience, etc.

(e) Cycling behavior (magnetic and thermal)

(f) Mechanical stability and vibrational behavior

(g) Heat Leakage

(h) Cool-down and warm-up times

2. Operational efficiency and cost considerations (relative to alignment, replacement, quench recovery, radiation effects, beam tune-up, etc)
3. Relative cost of entire accelerator facility during construction and operation periods (at same effective beam aperture for all magnet types).
4. Flexibility of future physics program permitted by magnet type characteristics.
5. Relative technical and financial exposure during construction and operating periods due to indeterminate (latent) characteristics inherent in each magnet type.

As described in Section 5.2.2 the Basic Magnet Type Evaluation Panel will make its evaluations and recommendation based on consideration of the three major areas: operational characteristics, potential reliability and cost. Following Basic Magnet Type selection, the CDG and participating laboratories will focus on developing the magnet design. An important part of this program will be systems tests.

A Task Force on the Magnet Systems Test Site was appointed by the CDG director in August 1984. This Task Force met at BNL,

SLAC, and FNAL during September and October, 1984. Their detailed report (SSC-SR-1001) was provided in October 1984. The report concludes that BNL and FNAL could provide the necessary basic facilities and attendant manpower required for the SSC magnet systems tests. The final selection and planning of this facility will be a part of the CDG effort in FY85. Implementation is expected to begin in FY86.

5.3 The FY86-87 Plan.

In the area of SSC Technical Systems, the magnet program will remain as the largest effort; however, other accelerator systems for the SSC including the injection accelerators will become a more substantial part of the total program.

Before the beginning of FY86 it is planned that the various considerations for magnet design will have been narrowed to a single optimum magnet style. Efforts will be focused on perfecting this design and producing a number of full size prototype units. Appropriate industrial involvement will be pursued in this task. After rigorous individual tests of magnets for field quality and performance, a system of magnets will be tested (the string test) at one of the existing laboratory sites. The purpose of the string test is to generate and answer questions that arise concerning those aspects of the SSC design that apply to relatively large groups of magnets as opposed to single magnet tests. In addition to being

used for system design and test, the String Test Facility will also be used to perform life tests on magnets and other accelerator components. The resulting information will be used to develop and verify designs in the following systems:

Magnet Systems
Magnet Cryogenics
Power Supplies
Quench Detection and Protection
Controls
Vacuum
Correction Coils
Safety

In FY86 the SSC program will also include engineering studies of quadrupoles and other special units such as correction element spools, injection system magnets, and insertion region magnet elements. The determination of the dipole magnet style (noted above) will enable Development efforts to be intensified on the associated cryogenic systems. This includes the relatively large refrigeration plants and the overall cryogenic distribution systems. Studies will be aimed to achieve maximum system reliability and minimum capital and operational costs.

An important effort will begin in FY86 for development of an optimum injection system for the SSC storage ring. The desired parameters of the injected beam will have been established in concert with the determination of the storage ring lattice and magnet characteristics. The injection system is currently visualized as a

sequence of three accelerators; a 1 Gev linac, a low energy booster synchroton (~70 Gev)and a high energy booster with a energy of 1 TeV. Studies will determine the optimum energy and beam characteristics of each of these injector accelerator systems. Work will begin on the overall lattice system for both booster accelerators and the required magnet parameters. In particular for the high energy booster a program will be inaugurated to provide prototype models of the superconducting magnet designs.

Other technical systems of the main storage ring will be studied to insure that appropriate designs can be achieved. These include the overall Vacuum Systems, Power Supplies Systems, Radio Frequency System, Abort System, Beam Diagnostic System, Instrumentation and Control Systems, and Safety Systems. It is expected that the system design philosophy for the computer control systems will be planned at an early stage. Components for the control system as well as for beam instrumentation may be tested at existing accelerators in order to achieve state-of-the-art designs with proven reliability.

Finally, as specific design concepts evolve for the various accelerator system, studies will be undertaken to understand and project the overall operational reliability and performance of the

SSC. For example, techniques for rapidly changing or repairing magnets must be considered and developed.

The Conventional Facilities activities in FY86 will be directed toward completing the Conceptual Design Report. Related work involves design concepts for accelerator systems tunnels and beam enclosures, power system, fire protection systems, communications, drainage, and cooling water systems.

A master plan for the layout of the central office, research offices, laboratories, assembly buildings and warehouse facilities will be developed together with appropriate structures for housing refrigerator systems, R.F. systems, power systems, and various support facilities. Roads and transportation systems will be of significant importance to both the construction and operation of a ring on the size scale of the SSC. The determination of construction methods and an optimized construction schedule will be an important part of the Conventional Facility effort in FY87.

The determination of the SSC lattice system and insertion regions will allow the conceptual designs of the experimental area structures to be developed. This effort must proceed in concert with plans for experimental detectors. The detector systems will be large and complex and will require significant Research & Development efforts by High Energy Physics research groups in FY86 and FY87.

6.0 PROGRAM SCHEDULE

The program schedule for major elements of the R&D program is shown in Figure 6-1. The associated program milestones are tabulated in Table 6-1.

The accelerator theory group activities are a critical point of the early R&D program. In conjunction with studies of beam limitations (instabilities, etc.) and performance, one of the most important tasks in the determination of the required aperture for the storage ring. This information and associated magnet costs are vital data for the magnet type selection. After the magnet selection, work will be directed toward optimizing all accelerator systems parameters, including the injector, as required for the Conceptual Design Report.

The Injection System Group will study a number of possible injections schemes. After magnet selection, the appropriate system will be optimized with respect to projected performance and reliability and described in the CDR.

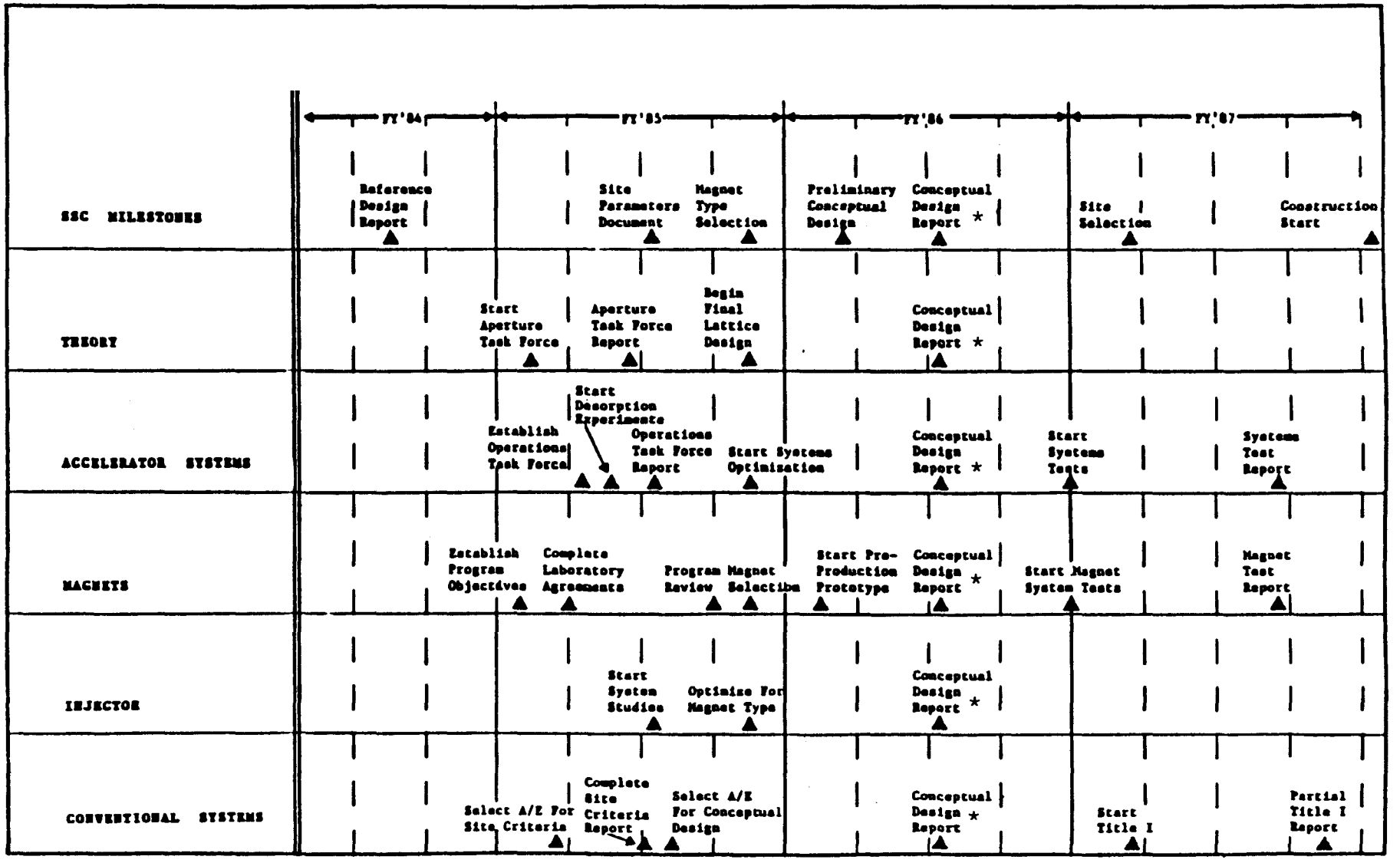
One of the first tasks of the Accelerator Systems Group is to provide detailed information regarding accelerator operations requirements. An operations task force will issue a report in April 1985. This data will be utilized in the magnet type selection process. After magnet selection, work will be directed to studies of cryogenic, vacuum, power supplies, R.F. Systems, Beam instrumentation, and control systems in preparation for the CDR. Prototype tests of developmental components will be conducted in FY86 and FY87.

Development programs for Superconducting magnets have been in progress at BNL, LBL, FNAL and TAC during FY84. By agreement with the CDG, these programs are now focused on providing information on a variety of magnet designs that might be appropriate for the SSC. Developmental magnet models are being fabricated, tested, and evaluated. This data, together with other information noted above, will be used to select the optimum magnet type for the SSC during the last quarter of FY85. After selection there will be an intense development program together with fabrication of a number of prototype magnets. These will be thoroughly tested in a system which closely simulates actual operating conditions. The system tests are projected to begin at the start of FY87.

The first task of the Conventional System Group is to develop a site criteria document of the SSC. An A/E firm has been selected to assist in the effort. The final report will be presented to DOE in April 1985. Afterwards efforts will be directed toward preparation of the Conceptual Design Report. Selection of an A/E firm for these activities is currently in progress. Beyond the CDR effort the start of Title I is planned for December 1986 at the time of site selection. This will help to provide an orderly and and efficient construction start at the beginning of FY88.

The program schedule is geared to accomplish the required research and development over a 3 year period prior to a construction start in FY 1988. The associated projected costs for this program are provided in the next section.

FIGURE 6-1
SSC PHASE I SCHEDULE



* Non Site Specific

TABLE 6-1

PHASE I PROGRAM MILESTONES

Date		Item
Oct 1984		Define Selection Criteria and Technical Information needed for Magnet Selection
Nov 1984		Established Primary SSC Design Features and SSC Phase I Program Plan Objectives
Apr 1985	*	Site Parameters Document
Apr 1985		Review Magnet Development Program
Jul 1985†	*	Magnet Design Type Selection
Dec 1985		Preliminary Conceptual Design
Feb 1986		Start Pre-Production Prototype Magnets
Mar 1986	*	Conceptual Design Report (non-site specific) and Other Documentation
Oct 1986		Magnet System Test Begins
Dec 1986	*	Site Selection by DOE
Jun 1987		Report on Systems Tests
Aug 1987		Recommended SSC Phase II Management and Procurement Plans Partial Title I Design Report
Oct 1987	*	SSC Construction Start (NTP)

* Denotes Primary Milestone

† Selection to be made during the last quarter of FY85.

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7. PROGRAM COSTS

A preliminary cost estimate for Phase I activities is provided in Table 7-1. The costs have been estimated for each of the three years of the program, FY 1985 - FY 1987; the SSC total R&D cost is estimated at $94M. The costs indicated are in FY 1985 dollars and represent the totals required for necessary staffing levels, equipment support, materials and component purchases, and relevant fabrications. The cost estimates reflect the scope and schedule accomplishments that each activity must achieve in order for the overall program goals to be met.

The Phase I R&D program described above covers the period FY 1985-87. It is anticipated that a strong R&D program will continue into FY 1988; the major objective of which will be to demonstrate the predicted magnet production rate and yield using the tooling and experience developed during the first three years. The specifics of this cost estimate may change as details of the R&D program evolve together with actual annual budgets. The program plan will be updated to reflect these conditions as required.

TABLE 7-1

SUPERCONDUCTING SUPER COLLIDER
PROJECTED R&D COSTS - PHASE I (M$)

	FY85	FY86	FY87
Program Total	25	28	66
(by Funding Category)			
- SSC Program	20	20	50
- Accelerator Related Programs	5	8	16
Program Total	25	28	66
(by Accelerator System)			
- Central Design Group	4.3	5.5	10.0
- Conventional Facilities	1.0	2.0	5.0
- Accelerator Systems	19.7	20.5	51.0
General Studies	0.5	0.5	1.0
Supercon Magnets	18.4	18.0	40.0
Cryo-Refrigeration	0.5	0.5	5.0
Vacuum	0.3	0.3	0.5
Power Supplies	-	0.2	0.5
R.F. Systems	-	-	0.3
Injection Systems	-	0.6	2.0
Abort	-	-	0.5
Instrumentation/Controls	-	0.4	1.0
Safety System	-	-	0.3

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APPENDIX A

SSC RESEARCH & DEVELOPMENT TOPICS

APPENDIX A

SSC Research and Development Topics

1.0 Technical Program Tasks

1.1. Program Management

- Organize and Plan the SSC Program
- Supervise and direct the SSC Program.
- Coordinate R&D activities with participatory laboratories and institutions
- Prepare the project proposal and Conceptual Design Report
- Prepare all required documentation including quality assurance and safety analysis reports
- Report to URA and DOE as required

1.2 Accelerator Theory

1.2.1 Calculations and Studies

- Study the dynamic aperture by numerical and analytical methods and correlate the results with the multipole content of magnets.
- Study models of persistent current effects and their correction including trade-offs with injection energy.
- Refine and optimize the lattice, including interaction region variants, and study chromatic aberration compensation.
- Study interaction region clustering, including consequences for beam-beam effect, backgrounds, and provision for low intensity test beams.
- Develop criteria for systems tolerances (e.g. power supply stability and ripple, etc.).
- Determine working points in tune space.
- Beam loss studies: energy deposition; consequences of uncontrolled beam loss, etc.
- Study requirements for slow beam extraction.
- Study implications of terrain following.

1.2.2 Development of Improved Computational Methods

- Extend the study of collective effects, including the improvement of impedance estimates, with wake-field codes.
- Develop improved computational methods in nonlinear dynamics to permit longer term tracking in real time, with the inclusion of the beam-beam effect, and the long range beam-beam effect with crossing angle.

1.2.3 Investigations on Existing Accelerators

- Investigate, using existing synchrotrons and colliders, particle lifetimes in superconducting rings, dynamic apertures, beam-beam effects, crossing angle effects, and multi-bunch operation.
- Investigate methods of beam control to provide adequate stability at the interaction points in the presence of possible vibrations and other sources of instability.

1.3 Accelerator Systems Design

- Develop the conceptual design for the SSC
- Investigate design options
- Initiate generic design studies, as required
- Integrate the technical systems

2.0 Site and Conventional Facilities

2.1 Development of Site Criteria

- Outline the technical needs of the SSC facility.
- Determine the range of acceptable physical, mechanical and utilities parameters for possible sites.

2.2 Generic A/E Studies

- Initiate parametric studies for design optimization.
- Undertake environmental, and safety analysis studies.
- Study the implications of terrain following.

2.3 Geotechnical Studies

- Do on-site investigations of the physical characteristics, including preliminary mapping and site summaries as required.

2.4 Conceptual Design Studies

- Study the possible configurations of conventional construction facilities on candidate sites.
- Prepare draft environmental impact and safety analysis information for final candidate sites.

2.5 Industrial Contracts

- Study methods of economical tunnel construction
- Arrange for consultant help from A/E firms.

3.0 Injector Systems

3.1 General Injector Studies

- Determine injected beam requirements for final main ring design.
- Optimize parameters for each of the injector accelerators.
- Investigate the modifications required to operate for $\bar{p}p$ colliding beams.
- Investigate the modifications required to operate for detector testing.
- Investigate the design necessary to yield low emittances

3.2 Linac

- Optimize the transition energies for the various types of accelerating structures in the Linac.
- Investigate various radio frequency quadrupole (RFQ) structures.
- Investigate various high velocity structures - SCL, Disk and Washer, Annular coupled, on-axis coupled, etc.
- Develop higher efficiency RF sources in the frequency range of 200-500 MHz.

3.3 Low Energy Booster (LEB)

- Develop ring magnet designs.
- Develop faster, stronger kickers and improved septum magnets.
- Develop lower impedance beam monitors and other devices to be installed inside the beam pipe.
- Investigate cost/performance of superconducting vs. normal copper coil magnets.

3.4 High Energy Booster (HEB)

- Develop ring magnet design and associated cryogenic systems.
- Demonstrate that superconducting magnet polarity can be reversed in a satisfactory manner.
- Develop superconducting septum magnets.
- Develop the design for slow beam extraction.

4.0 Collider Ring Systems

4.1 General Studies

- Test systems of magnets to determine system behavior.
- Verify installation and leak checking techniques, including development of related tooling and welding machines.
- Develop accurate, labor-efficient methods for installation, survey and magnet alignment.
- Analyze major causes of magnet quenches induced by the beam including those due to operator error and develop appropriate controls.
- Develop feedback techniques to keep small beam bunches in collision.
- Analyze the causes of downtime on existing accelerators with a view to achieving greater reliability in the SSC.

4.2 Superconducting Magnets

4.2.1 Superconductor

- Develop commercial production capability of NbTi with the highest possible value of J_c.
- Investigate the production of superconducting filaments of small diameters.
- Develop a rigorous program of short sample testing for the critical current density of the superconducting wire and cable which will obviate the need for cryogenic testing of every magnet.

4.2.2 Cabling

- Develop methods to extend to large quantities the industrial production of NbTi cable with higher critical current density.
- Investigate innovative cabling approaches including insulation and incorporate any improvements into large scale cable production.
- Develop cable making techniques that minimize the degradation due to the cabling and keystoning operations, including the investigation of post-cabling heat treatment for recovery of J_c.
- Determine a reasonable allowance for degradation of J_c in cabling.
- Develop methods to correct for the effects of persistent currents at low magnetic fields, including both self-energized and externally energized correction coil systems.
- Demonstrate the feasibility of using dry winding techniques with a collapsible mandrel for forming the coils in a collared coil design.

4.2.3 Magnet Research and Development

- Investigate the behavior of aluminum collars, and the cost/benefit of using more aluminum parts.
- Optimize the cold-mass support structure with respect to heat leak and to stability under expansion and contraction, particularly for very long magnets.
- Investigate characteristics and techniques of superinsulation.
- Make heat-load measurements on magnets, spool pieces, cryogenic valves and other components.
- Design optimized thermal shields to eliminate distortion due to thermal gradients.
- Develop procedures to measure the alignment of the magnetic field.
- Develop techniques for more complete determination of magnet characteristics from room temperature measurements, and for relating the measurements to cryogenic measurements done on a sampling basis.
- Develop magnet test equipment and methods for rapid and economical measurements of magnetic fields in small aperture, long magnets to accuracies of about 10^{-4}.
- Develop accurate, labor-efficient methods for internal magnet alignment, including verification that alignment is retained during cool-down.
- Investigate eddy current forces on the heat shields and helium piping inside the cryostat of the no-iron magnet under rapid quench conditions.
- Develop quality assurance procedures for all stages of manufacture.
- Develop mass-production methods for winding the dipole correction elements.
- Design, construct, and test a series of model magnets.
- Develop tooling that is appropriate to producing magnets at the required rate.

- Develop robotics to reduce labor costs in fabrication and installation of magnets.
- Construct a significant number of full-length "proof" magnets, using actual production tools and procedures, at high production rates.
- Prepare the refrigerator and cryogenic system for a string list.
- Test up to a kilometer long string of superconducting magnets.
- Establish criteria for evaluation of cyclic fatigue.
- Investigate various quadrupole options to determine the most economical design.
- Develop special superconducting magnets, such as high gradient quadrupoles and large bore dipoles for the interaction regions.
- Develop procedures to repair, retest and certify magnets.
- Develop handling techniques for very long magnets.
- Develop procedures to identify magnets that have to be replaced, such as observation of low quench current, voltage tap monitoring, or pickup loop voltage monitoring.
- Develop procedures for the transfer of superconducting magnet technology to industry, including development of tooling.

4.3 Cryogenics/Refrigeration

- Investigate the reliability/repairability of cold turbocompressors as cryogenic pumps.
- Develop cryogenic valves of low heat leak, high reliability, and low cost.
- Develop methods of construction for low heat-leak helium transfer lines at an economical cost.
- Study the operating experience of the Tevatron cryogenic system with a view to improvements in efficiency and reliability.
- Optimize and test a model recooler.
- Investigate and optimize screw compressor efficiencies.
- Develop efficient and expeditious purification techniques for the He refrigeration system.
- Develop a computer simulation of cryogenic systems.

4.4 Vacuum

- Measure the desorption due to synchrotron radiation, of hydrogen and other gases from cryogenic beam tubes.
- Develop leak detectors and techniques with sensitivities of order 10^{-11} torr /sec, on both warm and cold systems.
- Develop and test devices for making the beam tube walls and bellows electromagnetically smooth to reduce the longitudinal impedance.
- Verify the absence of beam induced multipactoring in materials exposed to the proton beam.
- Identify, (using computational methods),those particular conditions of bunch spacing and bunch intensity under which trapped stable electron orbits exist in the beam tube.
- Develop suitable cold valves for vacuum isolation and leak detection purposes and carry out an optimization study to determine the minimum number of valves needed.

4.5 Main Power Supplies/Quench Protection

- Develop a simple and fail-safe dynamic quench protection system.
- Investigate passive quench protection as a means of achieving potentially less expensive and more reliable systems.
- Investigate the regulation and tracking of multiple independent power supplies to one part in 10^{-4}.
- Calculate and measure transmission line modes of magnet systems.
- Develop reliable high current power leads for cryogenic use.

4.6 Correction Element Power Supplies

- Investigate the regulation and tracking of independent power supplies.
- Optimize power supply distribution and connections, including multiple-lead feedthrough.
- Study external vs. internal (cryogenic) connection of series elements.

4.7 RF Systems

- Identify the most cost effective operating frequency and type of RF equipment.
- Compute the expected SSC impedances in detail and the rise times of the various modes.

4.8 Injection Systems

- Investigate superconducting septum magnets.

4.9 Abort Systems

- Design and simulate abort systems to arrive at an optimal configuration.
- Study beam loss phenomena and their effects on superconducting magnets.

4.10 Beam Instrumentation

- Investigate superconducting amplifiers for use in special applications.
- Develop special beam instrumentation, such as Schottky scan electronics, flying wires, etc.

4.11 Controls

- Develop multi-level control system network designs.
- Analyze and test experimentally whether electronics can be placed in the tunnel with out radiation shielding.
- Analyze and develop redundant control systems.

4.12 Safety Systems

- Conduct cost/safety study of exit spacings.
- Analyze safety systems for operations.